Science of the Total Environment 409 (2011) 3073–3077

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Short Communication

Estimation of daily inhalation rate in preschool children using a tri-axial accelerometer: A pilot study ☆

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ARTICLE INFO

Article history:
Received 26 October 2010
Received in revised form 27 March 2011
Accepted 1 April 2011

Keywords:
Daily inhalation rate
Exposure assessment
Preschool children
Accelerometer
Activity monitoring
Time-activity

ABSTRACT

The activity of 5- to 6-year-old Japanese children (n = 29) was monitored for 3 consecutive days, including one weekend day, using an ActivTracer tri-axial accelerometer. The daily inhalation rate and time spent in sedentary, light, or moderate to vigorous levels of physical activity (MVPA) were estimated from the accelerometer measurements based on previously developed regression equations. The 3-day mean daily inhalation rate (STPD) was estimated at $8.3 \pm 1.4\ m^3\ day^{-1}$ in 10 subjects who completed 3 days of monitoring. The time spent in sedentary, light, or MVPA each day was 320, 415, and 81 min day^{-1}, respectively. Analysis of between-day reliability indicated that 3 days of monitoring with the ActivTracer tri-axial accelerometer provided an acceptable estimate of daily inhalation rate (intra-class correlation coefficient [ICC] = 0.892), but low to moderate reliability for the time spent in different levels of activities (ICC = 0.43 to 0.58). We observed a significant difference in the daily inhalation rate between weekdays and the weekend day, possibly due to differences in time spent in MVPA. This finding suggests that a weekend day should be included to obtain more reliable estimates of daily inhalation rate using an accelerometer.

1. Introduction

The inhalation rate is an essential factor for estimating the inhaled doses of air pollutants. In recent years, consideration of particular vulnerability and patterns of exposure in children has been an issue in the assessment of health risks associated with hazardous environmental pollutants (WHO, 2006). The average daily inhalation rate of $8.7\ m^3\ day^{-1}$ established for U.S. children aged between 1 and 12 years (U.S. EPA, 1997) is currently proposed for health risk assessment in Japanese children to calculate the inhaled doses of pollutants (MHLW, 2007). However, differences in body size and daily food intake between American and Japanese children would be expected to introduce bias in estimations of daily inhalation rate in Japanese children. An approach based on energy intake rate has also been reported to overestimate the daily inhalation rate in younger age groups by 7% to 35% compared with those evaluated by the doubly-labeled water (DLW) method (Brochu et al., 2006b).

The metabolic energy expenditure approach and the time–activity–ventilation (TAV) approach are the methods used to estimate daily inhalation rate in humans (Arcus-Arth and Blaisdell, 2007; Stifelman, 2007; Brochu et al., 2006a; U.S. EPA, 2006; Allan and Richardson, 1998; Layton, 1993; ICRP, 1975). Of the energy expenditure approaches available, a physiological approach that uses daily energy expenditure measured by the 'gold standard' DLW technique (IOM, 2005) provides the most accurate estimate of the daily inhalation rate in individuals during daily life. However, the ^{18}O isotope used in this technique is very expensive and collection of urine samples over a 2-week period is usually required, resulting in the test being unsuitable for studies with a large number of subjects. On the other hand, the TAV method is a traditional approach that estimates the daily inhalation rate using existing data of minute respiratory ventilation rate ($\dot{V}_E$) of various physical activities performed during daily life. While the advantage of this approach is that the $\dot{V}_E$ data used in the calculations are actual measurements, a critical issue is the limited availability of data on $\dot{V}_E$ values for a variety of children's activities. In order to fill these gaps in the data, Layton (1993) developed a time–activity energy expenditure approach that calculated daily inhalation rate using metabolically derived $\dot{V}_E$ as a product of basal metabolic rate (BMR), metabolic equivalent (MET) for an activity of interest, ventilatory equivalent (VQ),

☆ Sources of support: This study was supported in part by the Ministry of Environment of Japan. The contents of this article are solely the responsibility of the authors and do not necessarily represent the official views of the ministry.

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doi:10.1016/j.scitotenv.2011.04.006

and oxygen uptake rate. The strength of this "MET approach" is that it uses a $\dot{V}_E$ that corresponds to a variety of physical activities that people engage in during daily life, which can be estimated from MET values abundantly available in the literature. However, the limitation of this approach is that the MET value should not be used to calculate the cost of the children's activities (Torun, 1983; Puyau et al., 2004). Self-report based time–activity data used in the TAV and MET approaches (Allan and Richardson, 1998; U.S. EPA, 2006) also have limitations in objectivity and accuracy, especially in young children (Bender et al., 2005; Lichtman et al., 1992).

To overcome the issues described above, we introduced a new approach in a previous study that used an accelerometer to estimate $\dot{V}_E$ that corresponded to a range of physical activity levels in children during daily life (Kawahara et al., 2011). In the present study, we conducted 3 days of continuous monitoring of physical activity in preschool children during daily life. Using the regression equations developed in our previous study we estimated daily inhalation rate and time spent at different levels of physical activity intensity from minute-by-minute ActivTracer accelerometer measurements. The objective of the present study was to examine the between-day reliability of these summary variables over 3 days, including one weekend day. We also assessed the magnitude of under- or over-estimation of our daily inhalation estimates by comparing the values with published daily inhalation rates derived from daily energy expenditure measured by the DLW method.

2. Methods

2.1. Subjects

The participants in the present study were 29 Japanese preschool children aged 5 to 6 years (mean ± SD, 6.2 ± 0.2 years; range, 5.9–6.8 years). The boys (n = 16) and girls (n = 13) were recruited from a single kindergarten class in a suburb of Tokyo. Of those participants, 26 children had participated in our previous laboratory exercise test, in which we calibrated measurements with the ActivTracer tri-axial accelerometer against $\dot{V}_E$ measured with the Douglas bag method (Kawahara et al., 2011). The mean height of the participants was 116 ± 5 cm (range, 103–125 cm) and mean body weight was 20.0 ± 2.3 kg (range, 16.3–25.5 kg). No significant gender differences in body weight or height were observed (*t*-test, $P<0.05$). The experimental procedures and purpose and protection of personal information were explained thoroughly to the parents of each participant, and written consent was obtained before monitoring was initiated. The experimental protocol was approved by the ethics committee of the National Institute for Environmental Studies.

2.2. Data collection

The physical activity of the children was monitored for 3 consecutive days, including one weekend day (i.e., from Thursday morning to Sunday morning) during the period December 2006 to March 2007. The monitoring period was determined based on the results of previous studies (Trost et al., 2000; Janz et al., 1995) that indicated a 3-day period was the minimum duration required for reliable estimates of typical physical activity in children using an accelerometer. In addition, Trost et al. (2000) suggested including weekend days to ensure reliable assessment of physical activity in children using an accelerometer. In the present study, Thursday (day 1) and Friday (day 2) served as the weekdays, and Saturday (day 3) served as the weekend day. On weekdays during the monitoring period, the children attended kindergarten as usual. Their activity was monitored with an ActivTracer tri-axial accelerometer (AC-210A, 50 mm × 70 mm × 20 mm, 60 g, GMS Inc., Tokyo, Japan). The ActivTracer detects movements in the anteroposterior (*x*-axis), mediolateral (*y*-axis), and vertical (*z*-axis) directions. The output measure of the ActivTracer is the average of absolute values for acceleration in each direction and the synthetic values of the 3 axes (vector magnitude) for a time interval defined by the user. The monitor was set to record body acceleration at 60-second intervals, and was contained in a small nylon pouch worn on the subject's hip attached to an adjustable belt. The subjects were allowed to detach the monitor when sleeping, bathing, showering, and swimming. The parents were instructed to help their child wear the monitor continuously during all waking hours for 3 consecutive days. They were also given a time–activity log sheet to record the time the subjects detached the monitor and the activities the subjects engaged in while monitoring was discontinued. During the time the subjects were at the kindergarten, the time–activity log was completed by the study staff.

2.3. Data reduction

Periods of 5 min or longer of continuous non-detection of body acceleration and no record of the monitor being detached were considered as non-wearing times and were not included in the calculation of total minutes of monitoring. Subjects who had non-wearing times longer than 60 min per day, with the exception of times for sleeping, bathing, showering, or swimming, were regarded as poorly compliant with the monitoring protocol. Only subjects with 3 complete days of monitoring data were included in the estimation of daily inhalation rate and time spent at different levels of physical activity.

2.4. Estimation of the daily inhalation rate

The daily inhalation rate (Standard temperature, Standard Pressure, and Dry, STPD) was calculated by summing the $\dot{V}_{E,\,STPD}$ for each minute estimated from the ActivTracer measurements during the 24 hour period. $\dot{V}_{E,\,STPD}$ for each minute was estimated from the synthetic acceleration (AC_{xyz}) using the following Eqs. (1) and (2) developed in our previous study based on data obtained from 5 to 6 year-old children including subjects in the current study

$$\dot{V}_{E,\,STPD\,i} = 0.00086 \times AC_{xyz} + 0.20 \quad (1)$$

$$\dot{V}_{E,\,STPD\,i\ \ other\ \ than\ \ walking} = 0.00094\ AC_{xyz} + 0.35 \quad (2)$$

One of the two equations specific for the type of physical activity was used. This is because there are different accelerometer measurements — $\dot{V}_E$ relationships by the type of activity. The details of these procedures have been reported elsewhere (Kawahara et al., 2011). Eq. (1) was used as the default equation to estimate $\dot{V}_{E,STPD}$. If the synthetic acceleration of the activities of interest was within the range of 96–754 mG min^{-1}, the activities were classified as either 'walking' or 'other than walking' types using the discriminating Eq. (3) described below:

$$F = -3.31 + 5.98 \times \left(AC_z / AC_{xy}\right) - 0.017 \times AC_z \quad (3)$$

In this equation, *F* is a discriminant function, AC_z is vertical acceleration, and AC_{xy} is horizontal acceleration measured with the ActivTracer. If *F* was <0.207, the activity was classified as a type 'other than walking'. For such an activity, $\dot{V}_{E,STPD}$ was estimated from the synthetic acceleration using Eq. (2). For activity classified as 'walking,' $\dot{V}_{E,\,STPD}$ was estimated using Eq. (1).

Based on the previous study (Kawahara et al., 2011), the values of $\dot{V}_{E,\,STPD}$ during periods when the subjects had detached the monitor were assumed to be as follows: During sleeping, 0.16 L kg^{-1} min^{-1}, derived by dividing 0.18 L min^{-1} at rest and lying quietly by 1.1, on the assumption that the metabolic rate during sleep is 10% lower than at rest (IOM, 2005), during use of the toilet and watching TV, 0.21 L kg^{-1} min^{-1}; during eating, 0.25 L kg^{-1} min^{-1}; during dressing/undressing and bathing/showering, 0.51 L kg^{-1} min^{-1}; and playing board games, 0.26 L kg^{-1} min^{-1}(Kawahara et al., 2011). As reliable data regarding $\dot{V}_E$ values or the physical activity ratio (PAR) for swimming in young children are not currently available, data for subjects who swam during the monitoring period were excluded from the analysis in the present study.

2.5. Estimation of time–physical activity distribution

The daily duration spent either sedentary, in light level of physical activity (LPA), or in moderate to vigorous level of physical activity (MVPA) was estimated based on minute-by-minute accelerometer measurements and partly on the time–activity records. As a measure of the intensity of physical activity, we used PAR, the energy cost of an activity per unit time, which is defined as a multiple of BMR per minute (FAO, 2004). According to the classification of Puyau et al., 2004, PAR <1.5 = sedentary, PAR ≥ 1.5 and <3.0 = LPA, and PAR ≥ 3.0 = MVPA. The cut-off levels between sedentary and LPA and LPA and MVPA were 71 mG min^{-1} and 412 mG min^{-1}, respectively, and for types of activity 'other than walking,' the cut point between LPA to MVPA was 218 mG min^{-1} (Kawahara et al., 2011). Physical activity including using the toilet, watching TV, eating, and playing board games was considered sedentary (Tanaka et al., 2007; Kawahara et al., 2011), while dressing/undressing and bathing/showering were classified as LPA (Taylor et al., 1948; Yamamura et al., 2003).

2.6. Statistical analysis

Intra-class correlation coefficients (ICC) were calculated using repeated measures analysis of variance (ANOVA) in order to evaluate the between-day reliability of daily inhalation rate, and the average time spent over the 3 days either sedentary, in LPA, or in MVPA. Repeated measures ANOVA was carried out to detect significant group mean differences in average daily inhalation rate and time spent in each level of physical activity among the 3 days of monitoring with day of monitoring as the within-subject variable. If the result of the analysis was significant, Tukey's test was used to determine which days were different. Bland–Altman plots (Bland and Altman, 1986) were prepared to assess the agreement in daily inhalation rate between weekdays and the weekend day. Statistical significance was defined as $P<0.05$. All statistical analyses were performed with SPSS (ver. 15.0 for Windows, SPSS Inc. Tokyo, Japan).

3. Results

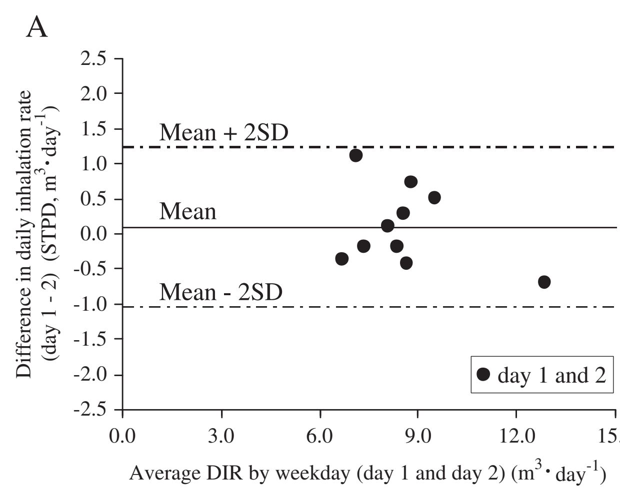
Of the total of 87 days of monitoring, complete 1-day data were available for 60 days. Complete 3-day monitoring data sets were obtained from 15 subjects. Of these, 5 subjects reported they had carried out swimming activities for 60 ± 29 min day^{-1} during the monitoring period. The 3-day mean monitoring time for the 10 subjects with complete 3-day monitoring data was 779 ± 51 min day^{-1}, and the daily inhalation rate (STPD) was estimated at 8.3 ± 1.4 m^3 day^{-1}. The 3-day mean daily times spent sedentary, in LPA, or MVPA were 320 ± 51 min day^{-1}, 415 ± 47 min day^{-1}, and 81 ± 34 min day^{-1}, respectively (Table 1). The ICC for the average daily inhalation rate (STPD) for 3 days was 0.961 ($P<0.001$). The single-day reliability coefficient for the daily inhalation rate (STPD) was 0.892 ($P<0.001$). The average daily inhalation rates (STPD) were significantly different between the 3 days ($P=0.01$). Fig. 1 shows the Bland–Altman plots of the differences for each subject against the mean daily inhalation rate (STPD). The mean difference in daily inhalation rate (STPD) between days 1 and 2 was 0.1 m^3 day^{-1} (95% CI: −1.03 and 1.23 m^3 day^{-1}). The mean difference in the daily inhalation rate (STPD) between days 1 and 3 was 0.63 m^3 day^{-1} (95% CI: −0.56 and 1.73 m^3 day^{-1}) and 0.54 m^3 day^{-1} (95% CI: −0.58 and 1.65 m^3 day^{-1})

Table 1
Mean (SD) for acceleration measurements, daily inhalation rates (STPD), and time spent in various activities estimated from accelerometer measurements in subjects with 3 complete days of monitoring data (N = 10).

Variable	Day 1	Day 2	Day 3	3 days mean
Average acceleration (mG min^{-1})[a]	155 ± 53	161 ± 59	111 ± 40	137 ± 46
Daily inhalation rate (m^3 day^{-1})	8.7 ± 1.6	8.6 ± 1.8	7.8 ± 0.8*	8.3 ± 1.4
Daily time for sleeping (min day^{-1})	609 ± 27	614 ± 40	648 ± 50**	624 ± 33
Daily time for sedentary (min day^{-1})	309 ± 61	311 ± 72	341 ± 77***	320 ± 51
Daily time in a light LPA (min day^{-1})	430 ± 79	418 ± 51	399 ± 57	415 ± 47
Daily time in MVPA (min day^{-1})	92 ± 47	98 ± 52	53 ± 38	81 ± 34

[a] Average acceleration = Σ acceleration measurement/number of monitored minutes.
* Significantly different from day 1 (P = 0.02) and day 2 (P = 0.03) based on ANOVA followed by Tukey test.
** Significantly different from day 1 (P = 0.02) and day 2 (P = 0.04).
*** Significantly different from day 2 (P = 0.04).

between days 2 and 3. The between-day reliability for mean daily time spent in LPA was acceptable, with an ICC = 0.63 ($P=0.03$), while it was



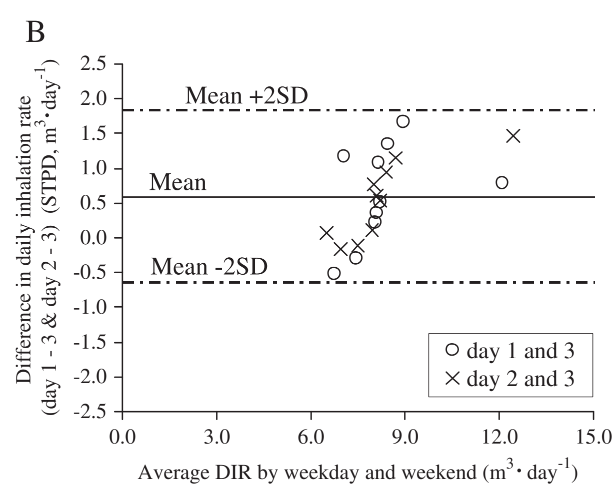


Fig. 1. Bland–Altman plots for the difference in daily inhalation rate (STPD) against mean daily inhalation rate (STPD) by weekday and weekend day. A: difference between days 1 and 2 against mean by days 1 and 2. B: difference between days 1 and 3 and days 2 and 3 against mean by days 1 and 2 and days 2 and 3.

low for sedentary, (ICC = 0.53, $P = 0.07$) and for MVPA (ICC = 0.42, $P = 0.149$).

4. Discussion

Our results indicated that between-day reliability was high for average daily inhalation rate estimated from ActivTracer measurements collected over 3 days, including a weekend day. However, in order to obtain a reliable estimate of daily time spent at different levels of physical activity, more than 3 days is needed. The between-day reliability of daily time spent at different levels of physical activity in this study was low compared with the study of Janz et al. (1995). In that study, the ICC for the percentage of the day spent in sedentary, moderate, or vigorous levels of activity monitored over 3 days in 7- to 15-year-old children using a CSA uni-axial accelerometer were 0.73, 0.70, and 0.71, respectively. This variability between the studies may be due to differences in evaluation of physical activity of children using tri-axial or uni-axial accelerometers (Kawahara et al., 2011) and also differences in the study subjects.

Fig. 2 shows comparison of mean daily inhalation rate (STPD) and distribution of the volume for the 4 categories of physical activity intensity in our subjects by day. Daily inhalation rate in the weekend day was on average 7% lower than during weekdays. The observed difference in the daily inhalation rate between weekdays and weekend days may be due to transition of time spent in MVPA to a lower level of physical activity on weekend days. We consider this result indicates that activity data also needs to be collected during weekend days in order to obtain a more reliable estimation of daily inhalation rate.

Table 2 shows comparison of mean daily inhalation rate expressed at body temperature, ambient pressure, and saturation with water vapor (BTPS) derived from daily energy expenditure measured with the DLW method in previous studies and current study. For comparison with estimates reported in earlier studies, our estimate of the daily inhalation rate of 8.3 $m^3\ day^{-1}$ expressed at STPD, corresponds to 10.1 $m^3\ day^{-1}$ (BTPS). Based on published data on daily energy expenditure measured with the DLW technique, Brochu et al. (2006a) estimated the daily inhalation rate (BTPS) of 5- to 6-year-old boys and girls as 8.6 $m^3\ day^{-1}$ (0.42 $m^3\ kg\ day^{-1}$) and 8.2 $m^3\ day^{-1}$ (0.40 $m^3\ kg\ day^{-1}$), respectively. Stifelman (2007), using the same approach as Brochu et al., reported the daily inhalation rate (BTPS) for 6-year-old boys and girls in an active day (physical activity level = 1.6 to 2.5 (IOM, 2005)), as 9.8 and 9.3 $m^3\ day^{-1}$, respectively (0.57 $m^3\ kg\ day^{-1}$ for both genders; body weight of 22.1 kg for boys and 21.3 kg for girls (U.S. EPA, 2008)). It should be noted that these studies used a VQ value of 27 derived from adult data (Layton, 1993) for estimating the daily inhalation rate of children. The VQ value is evidently lower than the observed value of 30 to 40 during sedentary to vigorous levels of physical activity in 6-year-old children (Kawahara et al., 2010). If we consider that the use of an adult VQ value would lead to a 30% under-estimation of the daily inhalation rate in young children, our estimation is therefore comparable to the rate measured in 5- to 6-year-old children by Brochu et al.

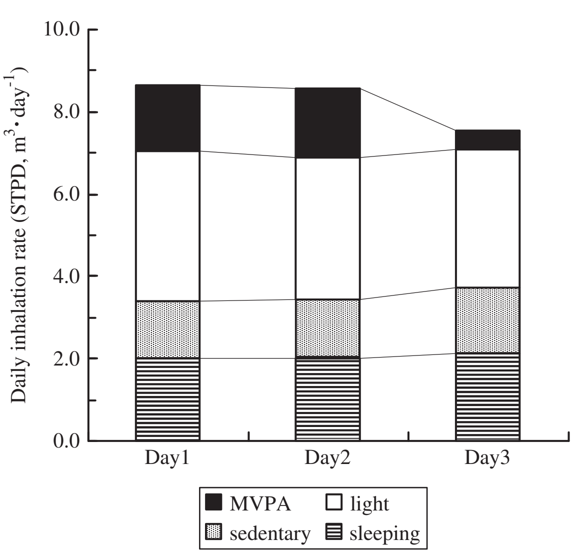


Fig. 2. Daily inhalation rate (STPD) and distribution of the volume for the 4 categories of physical activity intensity: sleeping, sedentary, light level of physical activity (LPA) and moderate to vigorous level of physical activity (MVPA).

Table 2
Comparison of the daily inhalation rate (BTPS) estimated in the current study with published values derived from daily energy expenditure measured with the DLW method.

Study	Age (years)	Gender	Daily inhalation rate (BTPS)[a]	
			(m^3 day)	($m^3\ kg\ day^{-1}$)
Brochu et al. (2006a,b)[b]	5–6	Boy	11.2 (8.6)	0.53 (0.42)
	5–6	Girl	10.6 (8.2)	0.51 (0.40)
Stifelman (2007)[b]	6	Boy	12.7 (9.8)	0.57[c]
	6	Girl	12.1 (9.3)	0.57[c]
This study	5–6	Both	10.1	0.51

[a] Values of daily inhalation rate ($m^3\ day^{-1}$) and normalized daily inhalation rate ($m^3\ kg\ day^{-1}$) in Brochu et al. and Stifelman are corrected with multiplying 1.3 in an assumption that the values in those studies are underestimated by 30% due to bias from the use of adult derived VQ values. Values in original article are in parentheses.
[b] Brochu et al. and Stifelman estimated daily inhalation rate by using physiologial approach using daily total energy expenditure measured with DLW method.
[c] Estimated by dividing the daily inhalation rate by the hypothetical body weight of 6-year-old boys and girls 22.1 and 21.3 kg, respectively.

While the strength of the approach we used in this study was to estimate the daily inhalation rate using an objective measure of physical activity, time–activity logs during periods when the accelerometer was not worn were still necessary to supplement this missing data. Our approach was also limited by the availability of $\dot{V}_E$ data in children. More data on $\dot{V}_E$ corresponding to a variety of physical activities observed during daily life in children will provide a more reliable estimate of their daily inhalation rate.

In conclusion, we obtained high between-day stability of the daily inhalation rate estimated from ActiveTracer measurements over 3 days, including one weekend day. However, more than 3 days are required to improve the between-day reliability of daily time spent in different levels of physical activity in preschool children when using ActivTracer. The daily inhalation rate of preschool children in the current study is possibly comparable to that estimated from the daily energy expenditure measured with the DLW method with consideration of potential bias from a physiological parameter derived from adults.

Acknowledgments

The authors thank all of the participants, their parents and teachers, and the administration of the kindergarten for their kind participation and support. We also wish to thank Mr. Suzuki T. at GMS Inc., Japan for technical advice on the operation and maintenance of the ActivTracer accelerometers.

References

Allan M, Richardson GM. Probability density functions describing 24-hour inhalation rates for use in human health risk assessments. Hum Ecol Risk Assess 1998;4(2): 379–408.
Arcus-Arth A, Blaisdell RJ. Statistical distributions of daily breathing rates for narrow age groups of infants and children. Risk Anal 2007;27(1):97-110.
Bender JM, Brownson RC, Elliott MB, Haire-Joshu DL. Children's physical activity: using accelerometers to validate a parent proxy record. Med Sci Sports Exerc 2005;37(8): 1409–13.

Bland JM, Altman DG. 1986 statistical method for assessing agreement between two methods of clinical measurement. Lancet 1986;1:308–10.

Brochu P, Ducre-Robitaille JF, Brodeur J. Physiological daily inhalation rates for free-living individuals aged 1 month to 96 years, using data from doubly labeled water measurements: a proposal for air quality criteria, standard calculations and health risk assessment. Hum Ecol Risk Assess 2006a;12(4):675–701.

Brochu P, Ducre-Robitaille JF, Brodeur J. Physiological daily inhalation rates for free-living individuals aged 2.6 months to 96 years based on doubly labeled water measurements: comparison with time–activity–ventilation and metabolic energy conversion estimates. Hum Ecol Risk Assess 2006b;12(4):736–61.

FAO. Human energy requirements. Report of a joint FAO/WHO/UNU expert consultation, Rome, 17–24 October 2001; 2004. p. 35–52.

ICRP (International Commission on Radiological Protection). Report of the task group on reference man. Tokyo Japan: Elsevier Science; 1975.

IOM (Institute of Medicine). Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids (macronutrients). Washington, DC: Food and Nutrition Board, National Academy Press; 2005. p. 880–935.

Janz KF, Witt J, Mahoney LT. The stability of children's physical activity as measured by accelerometry and self-report. Med Sci Sports Exerc 1995;27:1326–32.

Kawahara J, Tanaka C, Tanaka S. Estimation of minute respiratory ventilation rate of preschool children using tri-axial accelerometer. J Jpn Soc Atmos Environ 2010;45(5):235–45.

Kawahara J, Tanaka S, Tanaka C, Hikihara Y, Aoki Y, Yonemoto J. Estimation of respiratory ventilation rate of preschool children in daily life by using an accelerometer. J Air Waste Manage Assoc 2011;61:46–54.

Layton DW. Metabolically consistent breathing rates for use in dose assessments. Health Phys 1993;64(1):23–36.

Lichtman SW, Pisarska K, Berman ER, Pestone M, Dowling H, Weisel H, et al. Discrepancy between self-reported and actual caloric intake and exercise in obese subjects. N Engl J Med 1992;327(27):1893–8.

MHLW (Ministry of Health and Labor Welfare, Japan). Pharmaceutical and Food Safety Bureau. Guideline for assessing health risk of pesticide used indoor environment (a proposal). http://www.env.go.jp/water/dojo/noyaku/hisan_risk/hyoka_tih/com08/mat03.pdf. 2007 November.

Puyau MR, Adolph AL, Vohra FA, Zakeri I, Butte NF. Prediction of activity energy expenditure using accelerometers in children. Med Sci Sports Exerc 2004;36(9):1625–31.

Stifelman M. Using doubly-labeled water measurements of human energy expenditure to estimate inhalation rates. Sci Total Environ 2007;373(2–3):585–90.

Tanaka C, Tanaka S, Kawahara J, Midorikawa T. Tri-axial accelerometry for assessment of physical activity in young children. Obesity 2007;15(5):1233–41.

Taylor CM, Pye OF, Caldwell AB. The energy expenditure of 9-to-11-year-old boys and girls (1) standing, drawing and (2) dressing and undressing. J Nutr 1948;36:123–31.

Torun B. Inaccuracy of applying energy expenditure rates of adults to children. Am J Clin Nutr 1983;38(5):813–4.

Trost SG, Pate RR, Freedson PS, Sallis JF, Taylor WC. Using objective measures with youth: how many days of monitoring are needed? Med Sci Sports Exerc 2000;32:426–31.

U.S. EPA. Exposure factors handbook. Washington, DC: National Center for Environmental Assessment. Office of Research and Development; 1997.

U.S. EPA. Metabolically-derived human ventilation rates: a revised approach based upon oxygen consumption rates. External review draft. Washington, DC: Office of Research and Development. National Center for Environmental Assessment; 2006.

U.S. EPA. Child-specific exposure factors handbook. Washington, DC: National Center for Environmental Assessment. Office of Research and Development; 2008.

WHO. IPCS principle for evaluating health risks in children associated with exposure to chemicals. Environmental health criteria, 237. Geneva, Switzerland: WHO Press; 2006.

Yamamura C, Tanaka S, Futami J, Oka J, Ishikawa-Takata K, Kashiwazaki H. Activity diary method for predicting energy expenditure as evaluated by a whole body indirect human calorimeter. J Nutr Sci Vitaminol 2003;49:262–9.